ECE 322L
Electronics 2

02/06/20 - Lecture 6

Amplifiers: models and characteristics

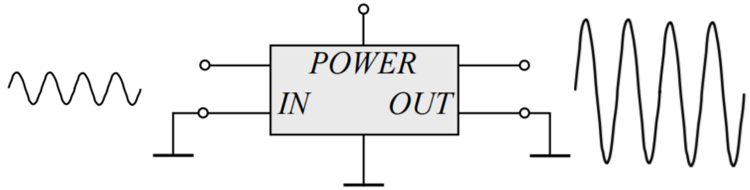
FET-based amplifiers: basic configurations

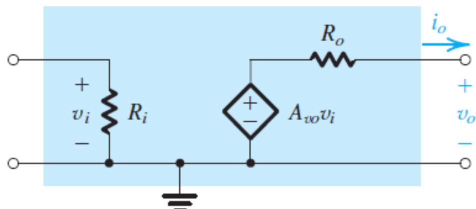
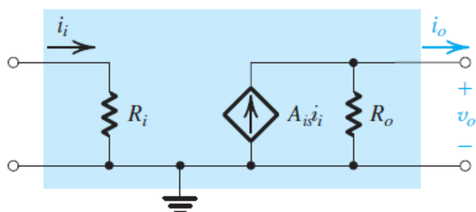
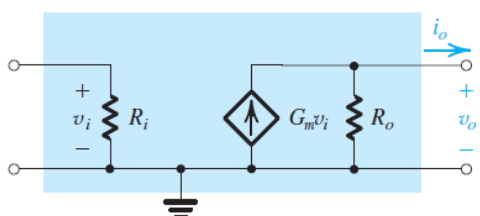
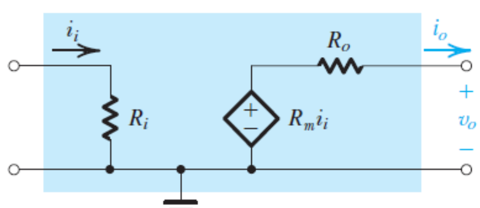
Common source amplifiers

Updates and Overview

- Homework 2 and Lab 3 are online
- Amplifiers: Models and Characteristics (S&S 1.5.1, 1.5.3, 1.5.5, 5.6.2)
- FET amplifiers configurations: overview (Neamen 4.2, S&S 5.6.1)
- Common source (CS) amplifier configurations (Neamen 4.3, S&S 5.6.3, 5.6.4)

Amplifiers: Models and Characteristics

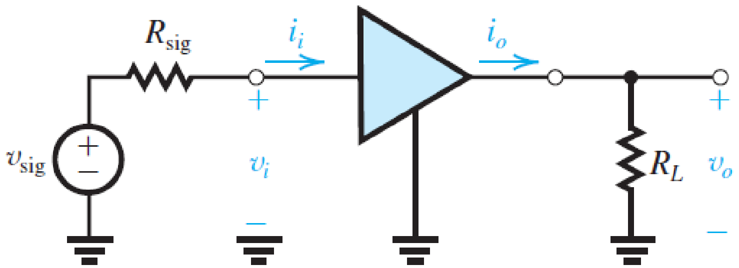


Type	Circuit Model	Gain Parameter
Voltage Amplifier		Open-Circuit Voltage Gain $A_{vo} \equiv \left.\frac{v_o}{v_i}\right\rvert_{i_o=0}$ (V/V)
Current Amplifier		Short-Circuit Current Gain $A_{is} \equiv \left.\frac{i_o}{i_i}\right\rvert_{v_o=0}$ (A/A)
Transconductance Amplifier		Short-Circuit Transconductance $G_m \equiv \left.\frac{i_o}{v_i}\right\rvert_{v_o=0}$ (A/V)
Transresistance Amplifier		Open-Circuit Transresistance $R_m \equiv \left.\frac{v_o}{i_i}\right\rvert_{i_o=0}$ (V/A)

Important characteristics or performance parameters of an amplifier

- Input resistance
- Output resistance
- Open circuit/Short circuit gain

Voltage Amplifier



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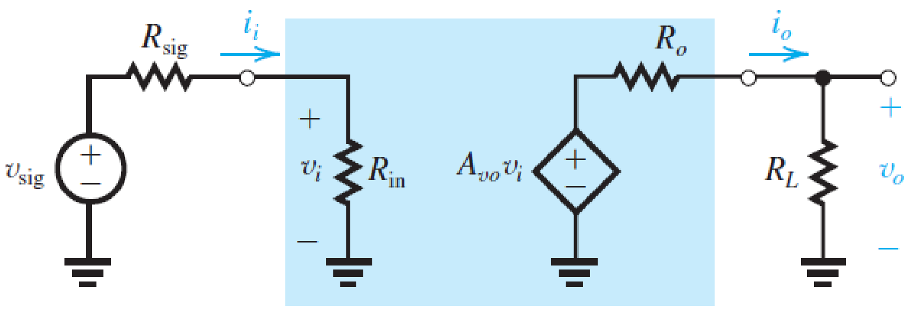
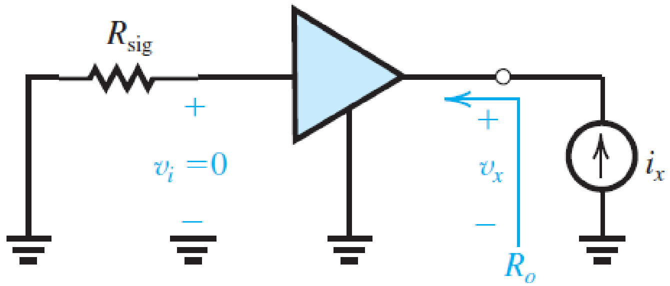


(b)



(c)

<u>Definitions</u>

Input resistance $R_{in} = \frac{v_i}{i_i} = R_i$

Open circuit amplifier gain (R_L infinite)

$$A_{vo} = \frac{v_o}{v_i}$$

Total amplifier gain (R_L finite)

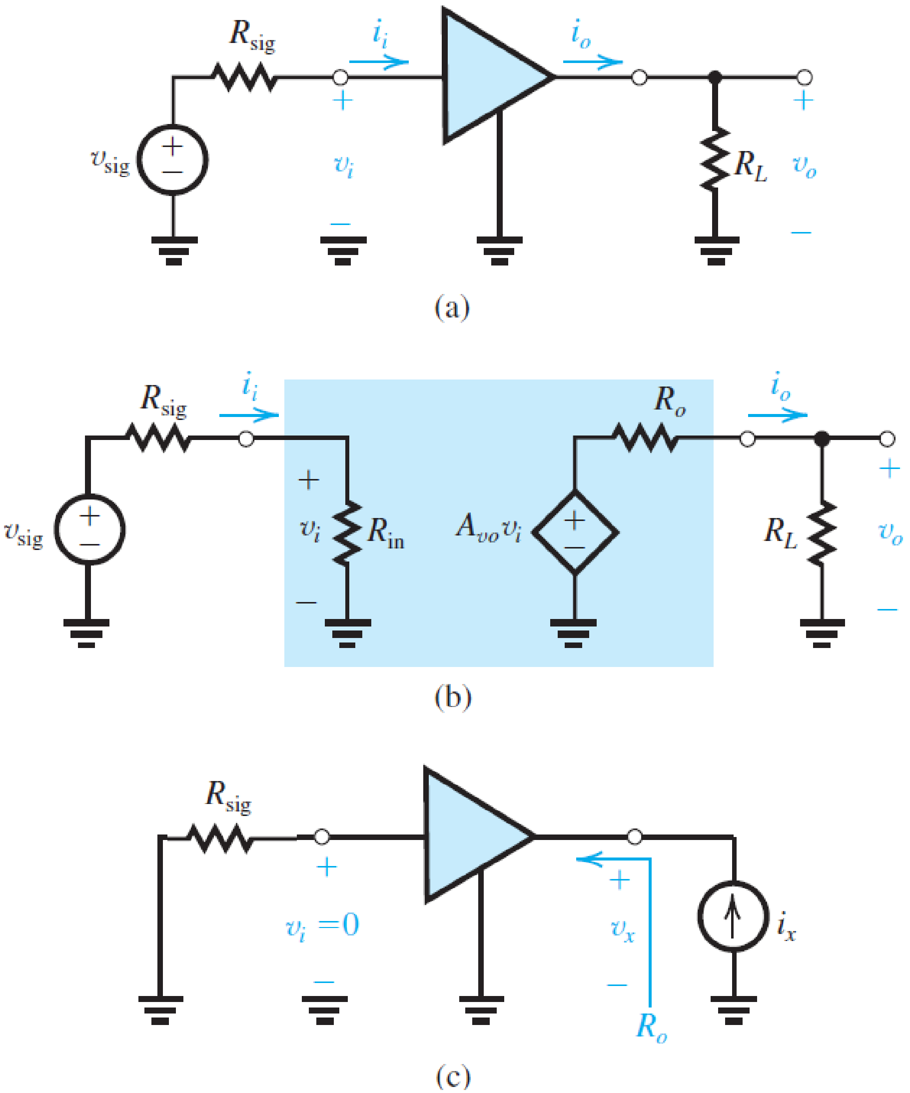
$$A_v = \frac{v_o}{v_i} = A_{vo}\frac{R_L}{R_L+R_o}$$

Overall Gain $G_v = \frac{v_o}{v_{sig}} = A_v\frac{R_i}{R_i+R_{sig}}$

Output resistance

$$R_{out} = \frac{v_x}{i_x} = R_o$$

Voltage Amplifier



Desired characteristics

- Input resistance

  Infinite

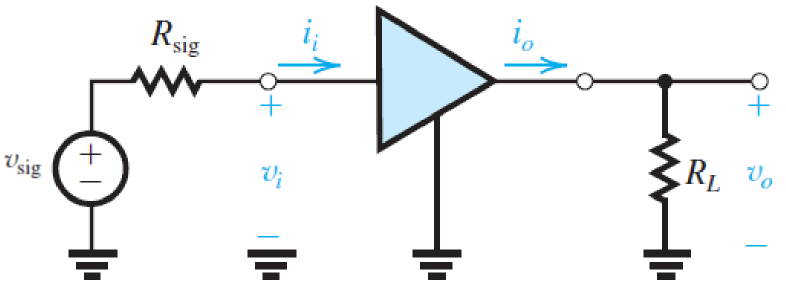
- Output resistance

  Zero

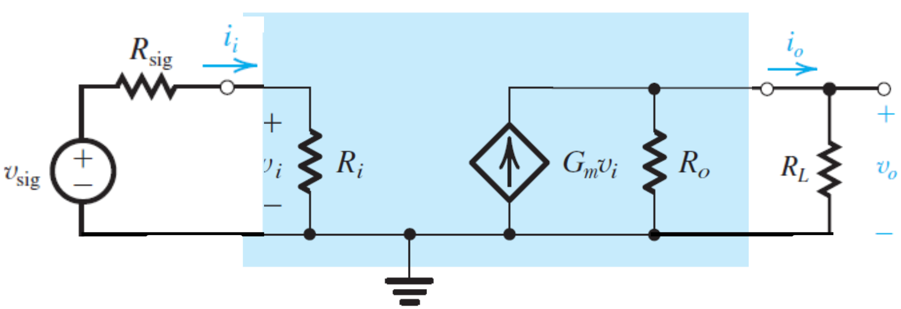
- Open circuit gain

  High

Transconductance Amplifier



(a)



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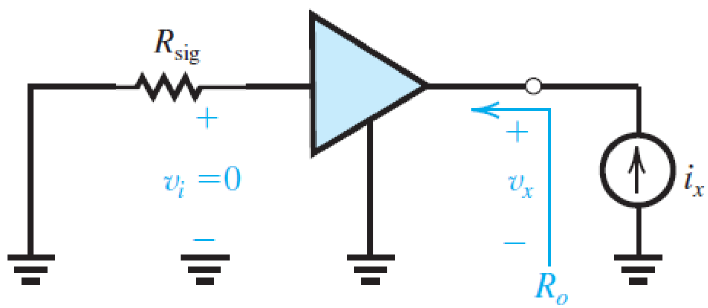


(c)

Definitions

Input resistance $R_{in} = \frac{v_i}{i_i} = R_i$

Short-circuit amplifier gain (R_L =0)

$$A_o = \frac{i_o}{v_i} = G_m$$

Total amplifier gain (R_L finite)

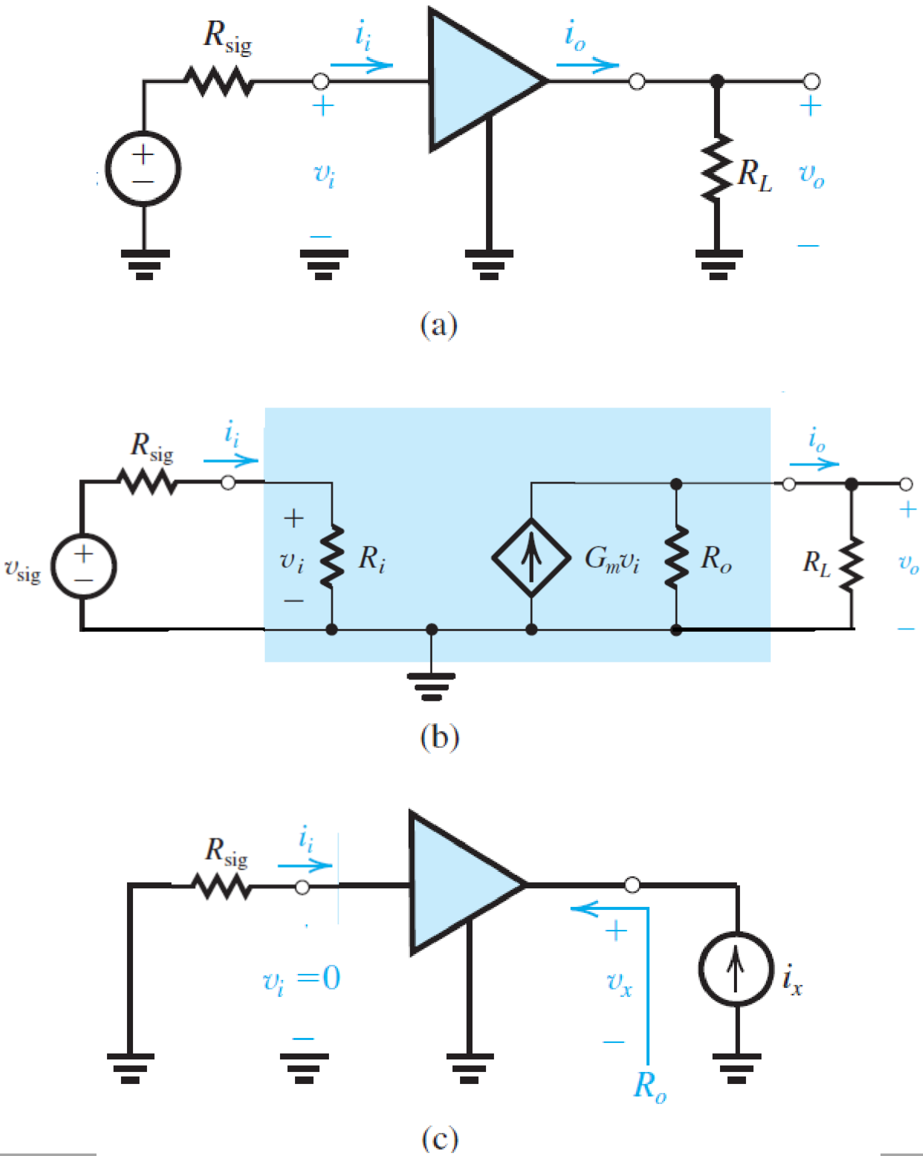
$$A_V = \frac{i_o}{v_i} = A_o \frac{R_o}{R_L + R_o}$$

Overall Gain $G_V = \frac{i_o}{v_{sig}} = A_V \frac{R_i}{R_i + R_{sig}}$

Output resistance

$$R_{out} = \frac{v_x}{i_x} = R_o$$

Transconductance Amplifier



Desired characteristics

- Input resistance

  Infinite

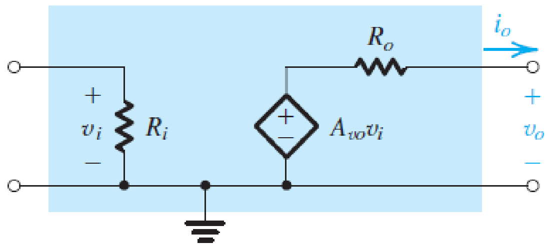
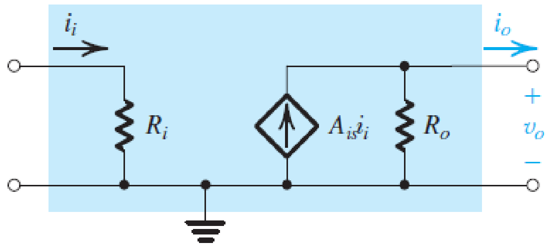
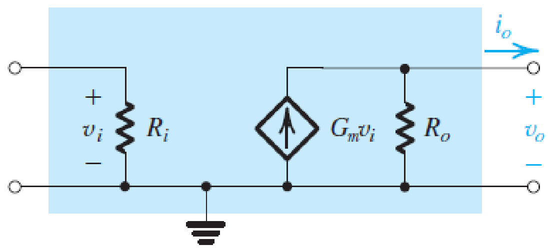
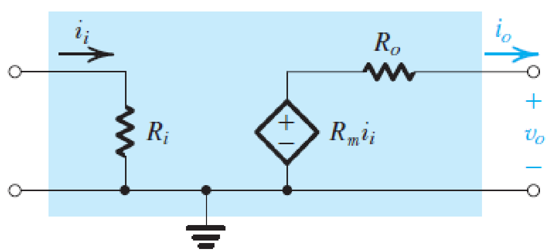
- Output resistance

  Infinite

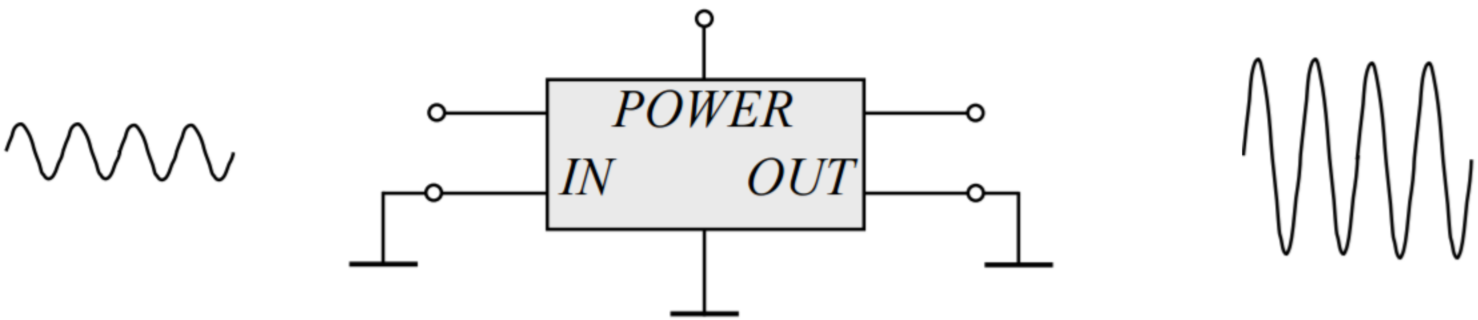
- Transconductance

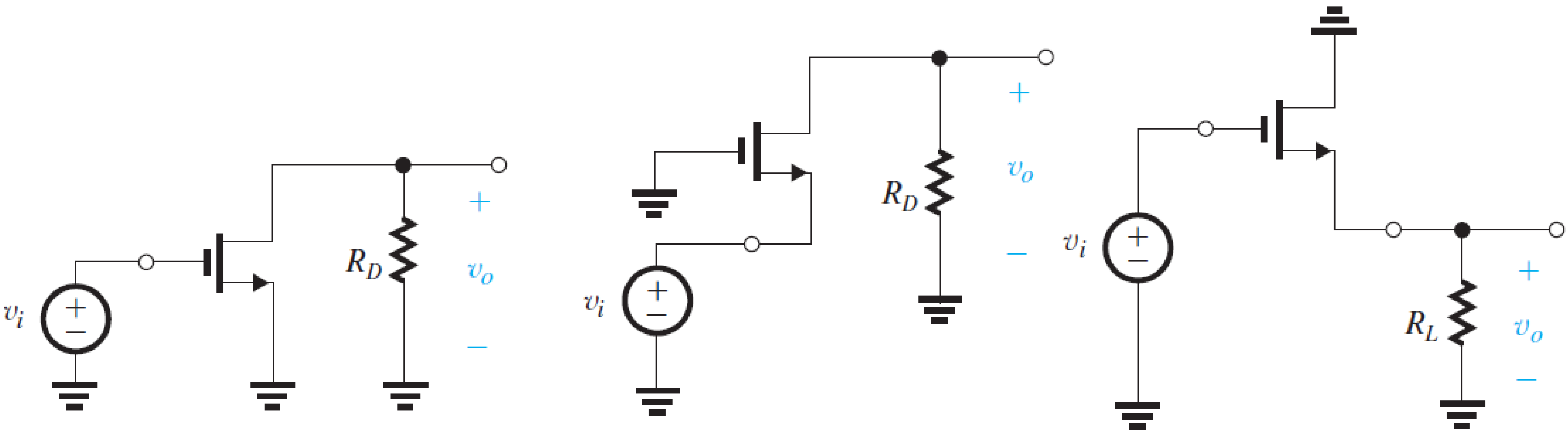
  High

Amplifiers: Models and Characteristics

Type	Circuit Model	Gain Parameter	Ideal Characteristics
Voltage Amplifier		Open-Circuit Voltage Gain $A_{vo} \equiv \left.\frac{v_o}{v_i}\right\|_{i_o=0}$ (V/V)	$R_i = \infty$ $R_o = 0$
Current Amplifier		Short-Circuit Current Gain $A_{is} \equiv \left.\frac{i_o}{i_i}\right\|_{v_o=0}$ (A/A)	$R_i = 0$ $R_o = \infty$
Transconductance Amplifier		Short-Circuit Transconductance $G_m \equiv \left.\frac{i_o}{v_i}\right\|_{v_o=0}$ (A/V)	$R_i = \infty$ $R_o = \infty$
Transresistance Amplifier		Open-Circuit Transresistance $R_m \equiv \left.\frac{v_o}{i_i}\right\|_{i_o=0}$ (V/A)	$R_i = 0$ $R_o = 0$

Basic configurations for FET amplifiers



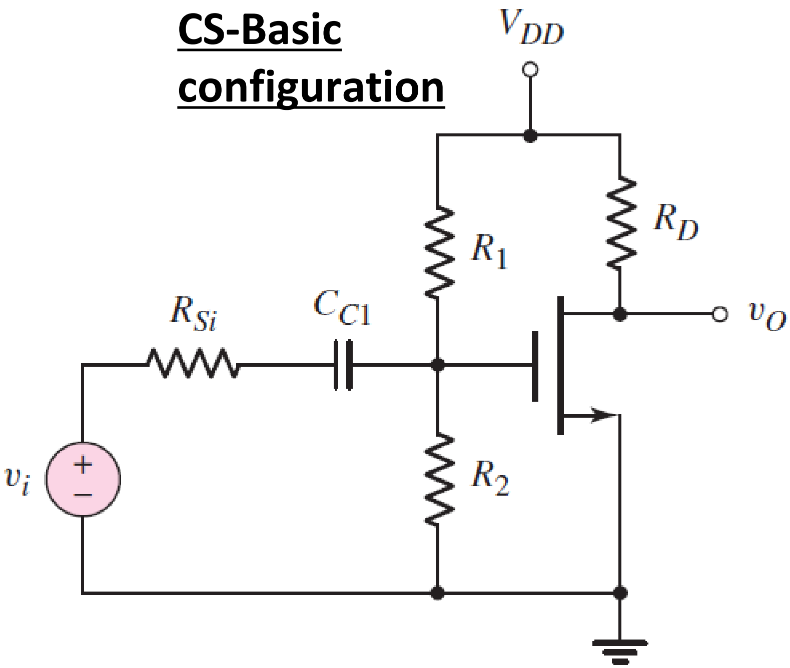


(a) Common Source (CS) (b) Common Gate (CG) (c) Common Drain (CD)

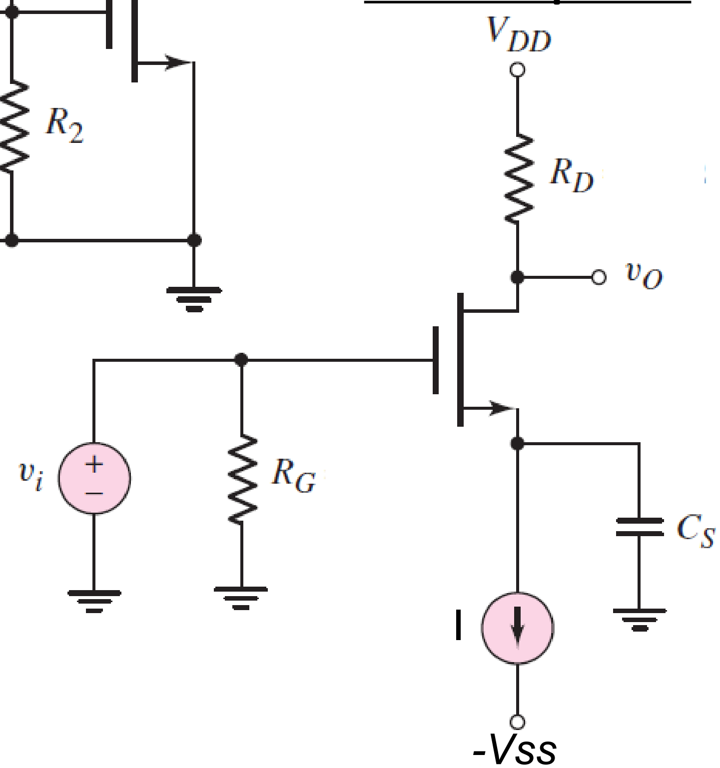
There are three basic configurations for connecting the MOSFET as an amplifier. Each of these configurations is obtained by connecting one of the three MOSFET terminals to ground, thus creating a two-port network with the grounded terminal being *common* to the input and output ports.

Common source (CS) Amplifiers

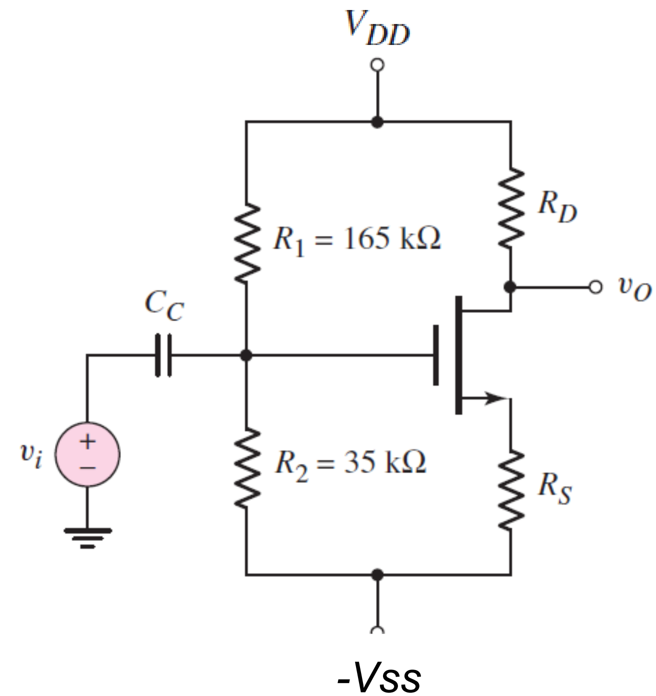
CS-Basic configuration



CS w/ bypass source capacitor

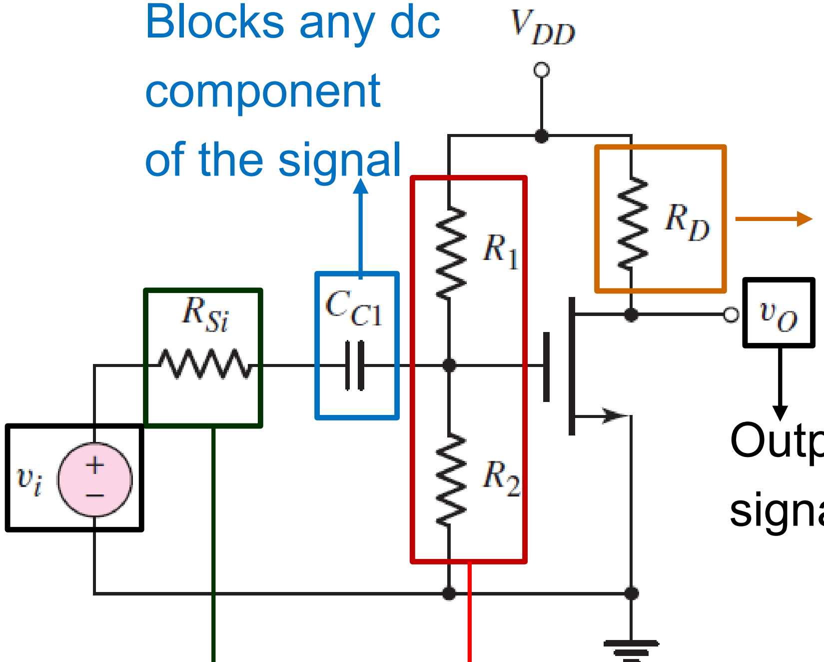


CS w/ source resistor



Common Source (CS) Amplifier

Blocks any dc component of the signal



R_D determines the Q point and acts as an internal load in ac. Note: The load can also be the input resistance of the next amplification stage in a multi-stage amplifier.

Input signal

Output signal

Determine the Q point along with V_{DD} and R_D

Internal resistance of a signal source or Thevenin equivalent of the output circuit of another amplifier stage.

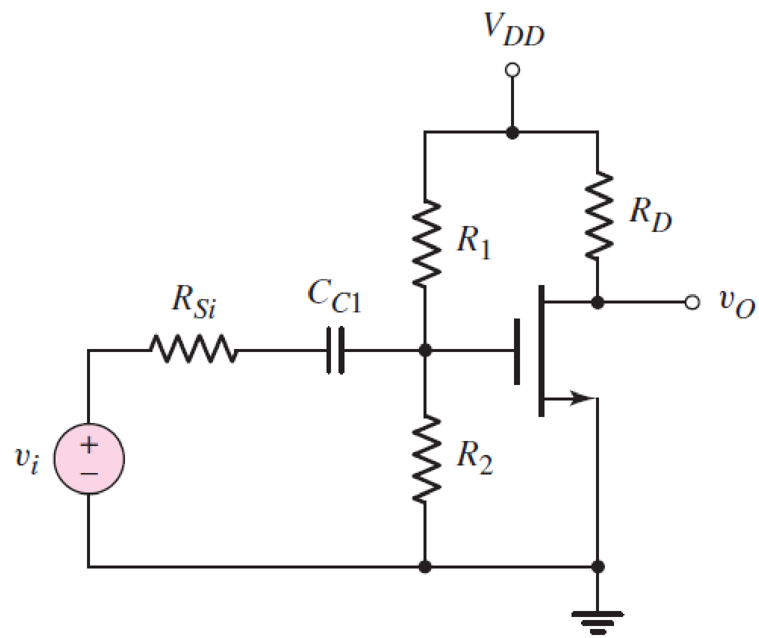
C_{c1} ~10s μF. This value guarantees a much smaller capacitor impedance than R_{si} for signal with frequencies higher than 2 kHz.

$$|Z_C| = \frac{1}{2\pi f C_C} = \frac{1}{2\pi(2\times 10^3)(10\times 10^{-6})} \cong 8\,\Omega$$

Cc1 can then be replaced with a short-circuit in ac analysis of high frequency signals

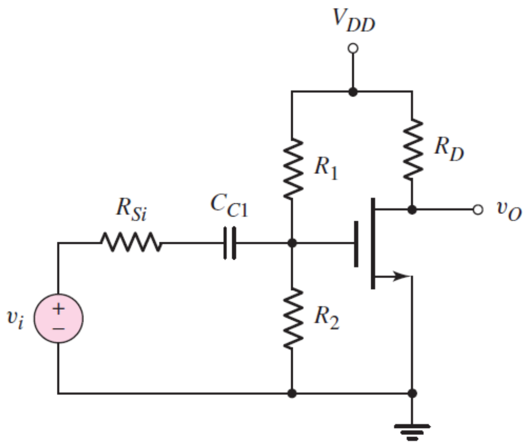
In-class Problem 1

Sketch the DC and the AC and the small-signal equivalent circuit of the common source amplifier below. Determine the expressions for the input and output resistance, for the open circuit voltage gain, the amplifier gain and the overall voltage gain. Assume the frequency of the input signal is midrange, i.e., high enough for the coupling capacitor C_{C1} to act as a short circuit in ac but low enough for the gate capacitor to act as an open circuit in AC.

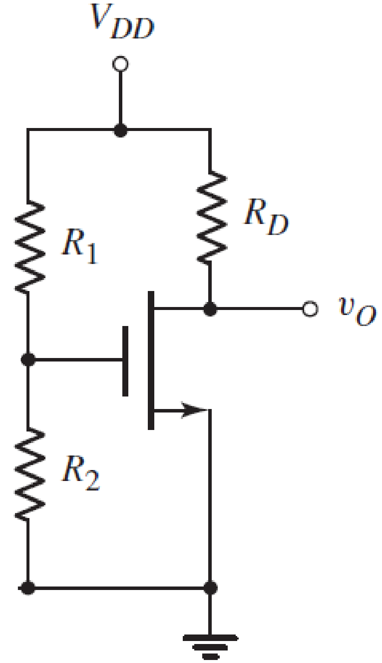


Consider $\lambda \neq 0$

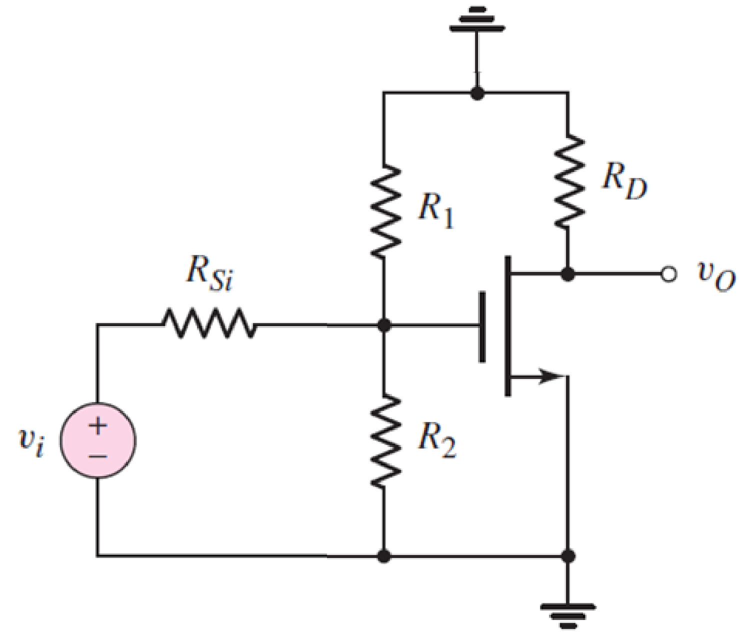
In-class Problem 1, Solution



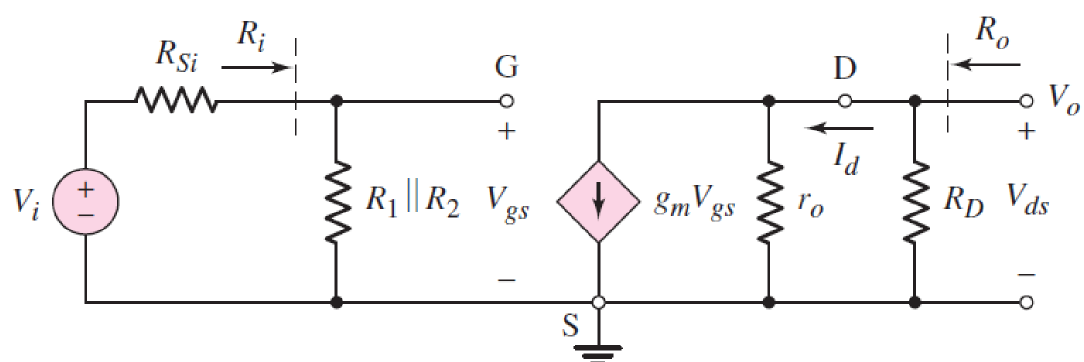
DC circuit



AC circuit

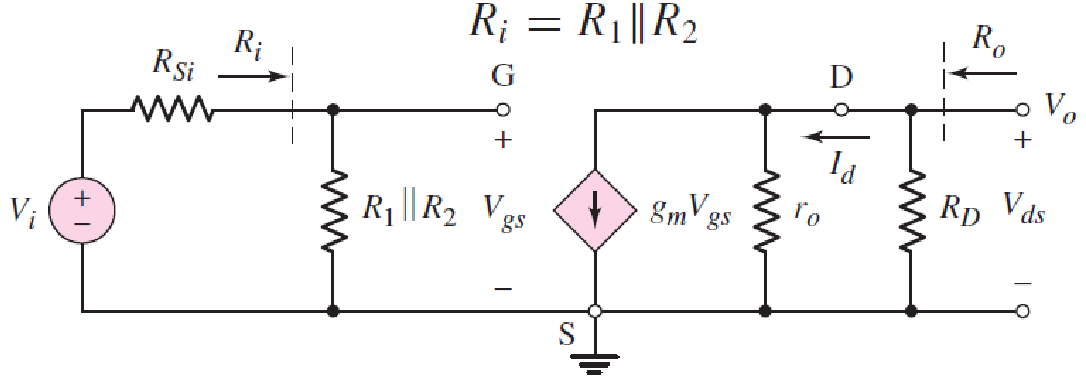


Small-signal equivalent circuit

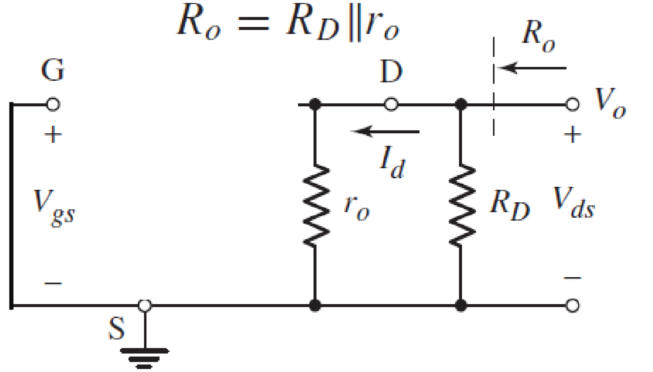


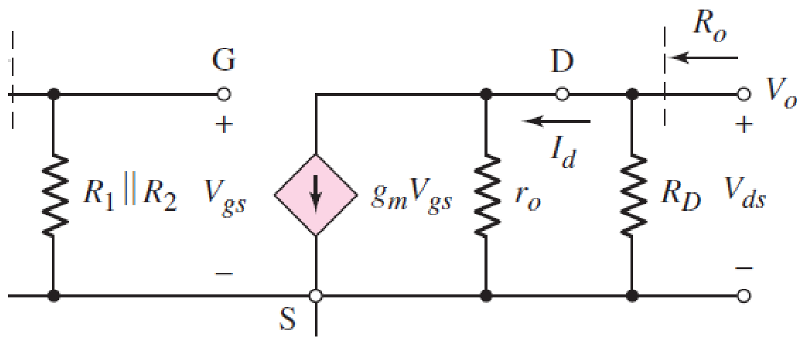
In Class Problem 1, Solution

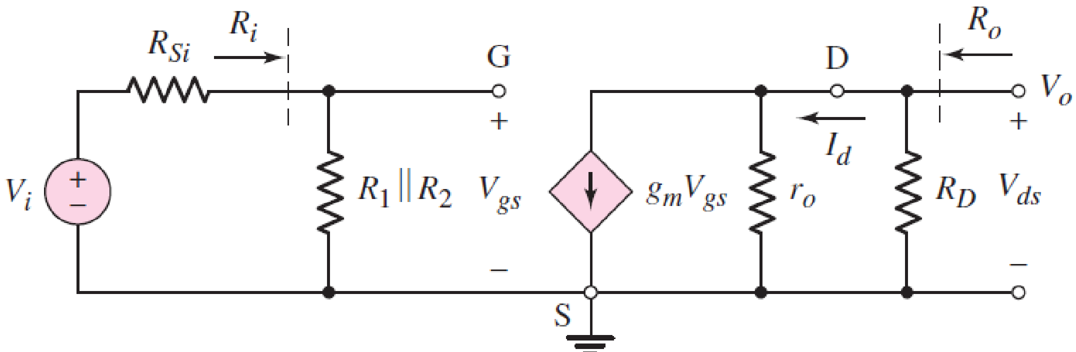
$$R_i = R_1 \| R_2$$



$$R_o = R_D \| r_o$$







Open circuit voltage gain ($R_L = \infty$)

$$A_{vo} = \frac{V_o}{V_i} = -g_m(r_o \parallel R_D)$$

Total voltage gain

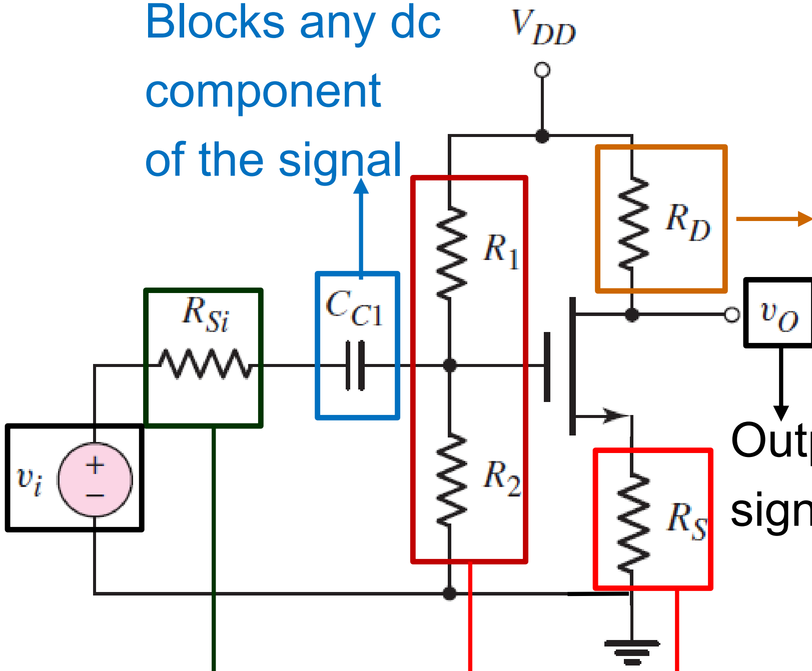
$$A_v = \frac{V_o}{V_i} = -g_m(r_o \parallel R_D)$$

Overall voltage gain

$$G_v = \frac{V_o}{V_i} = -g_m(r_o \parallel R_D)\frac{R_i}{R_i + R_{si}}$$

Common Source (CS) Amplifier w/ R_s

Blocks any dc component of the signal



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Note: The load can also be the input resistance of the next amplification stage in a multi-stage amplifier.

Input signal

Output signal

Determine transistor bias along with V_{DD} and R_D

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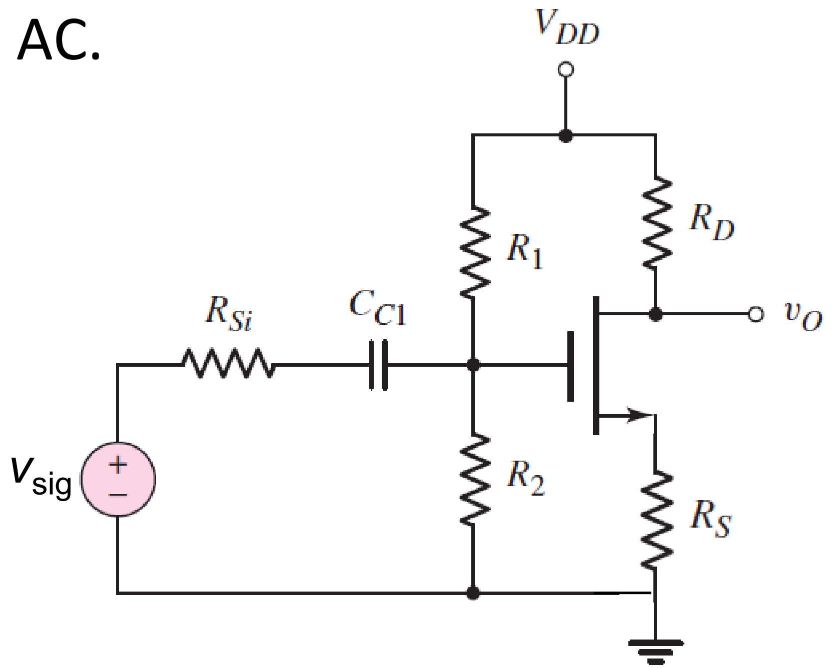
C_{c1} is typically of the order of ~10s μF. This value guarantees a much smaller capacitor impedance than R_{si} for signal with frequencies higher than 2 kHz.

$$|Z_C| = \frac{1}{2\pi f C_C} = \frac{1}{2\pi(2\times 10^3)(10\times 10^{-6})} \cong 8\,\Omega$$

C_{c1} can then be replace with a short-circuit in ac analysis of high frequency signals

In-class Problem 2

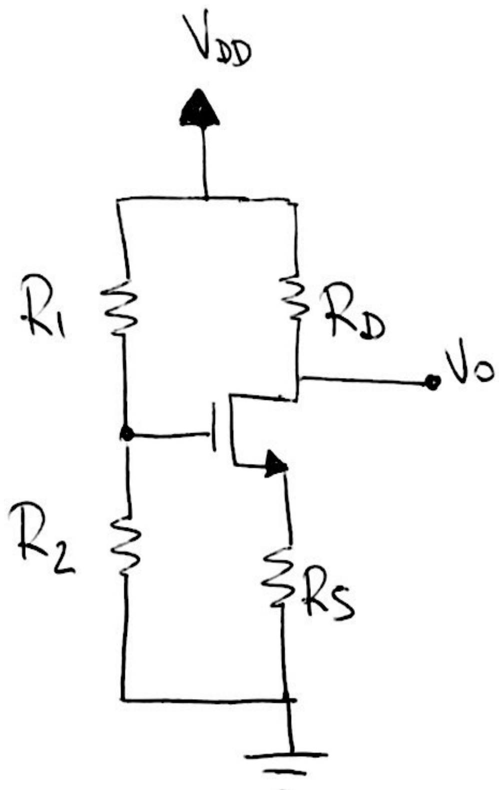
Sketch the DC and the AC and the small-signal equivalent circuit of the common source amplifier below. Determine the expressions for the input and output resistance, for the open circuit voltage gain, the amplifier gain and the overall voltage gain. Assume the frequency of the input signal is midrange, i.e., high enough for the coupling capacitor C_{C1} to act as a short circuit in ac but low enough for the gate capacitor to act as an open circuit in AC.



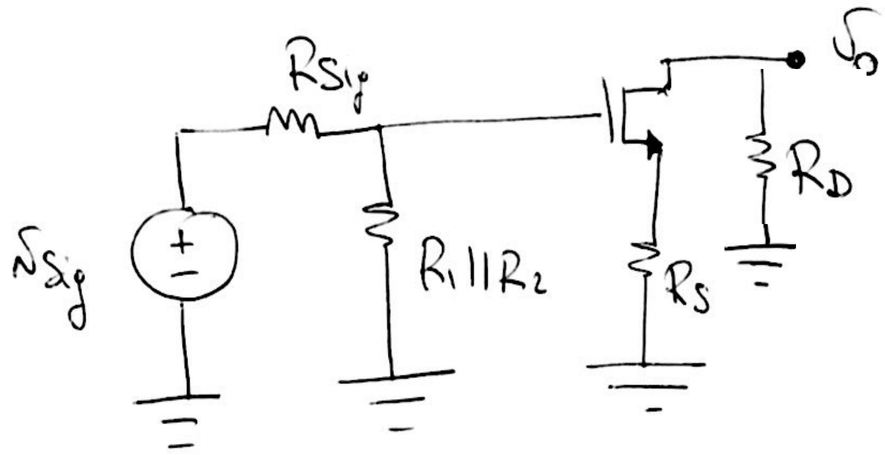
Consider $\lambda \neq 0$

In class Problem 2, Solution

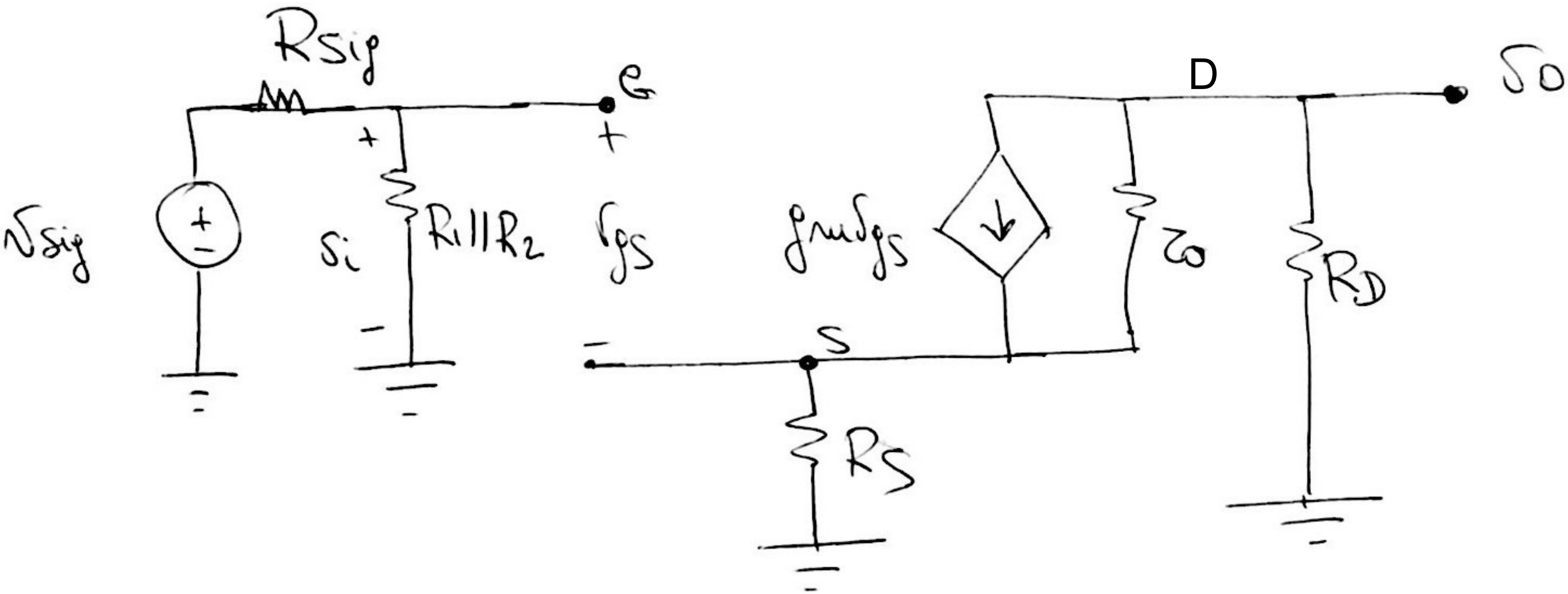
DC circuit



AC circuit

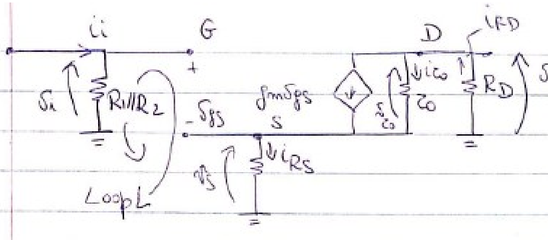


In class Problem 2, Solution



In-class Problem 2, Solution

Input resistance and open-circuit voltage gain



$R_{in} = \dfrac{v_i}{i_i} = R_1 // R_2$ (1)

$A_{vo} = A_v$ (2)

$v_o = -i_{RD} \cdot R_D$ (3) (Notice the $-$ to satisfy the passive sign convention).

$i_{RD} = i_{RS}$ (4)

$i_{RS} = \dfrac{v_S}{R_S}$ (5)

$v_o = -\dfrac{R_D}{R_S} v_S$ (6) (Combining (3) and (5) I obtain (6))

↳ we need to determine v_S in terms of v_i.

$v_S = v_i - v_{gs}$ (7) $\Rightarrow v_{gs} = v_i - v_S$ (8) KVL @ Loop L

$i_{RS} - g_m v_{gs} - i_{ro} = 0$ (9) KCL @ S

$\dfrac{v_S}{R_S} - g_m(v_i - v_S) - \dfrac{v_{ro}}{r_o} = 0$ (10)

$v_{ro} = v_o - v_S$ (11)

$\dfrac{v_S}{R_S} - g_m(v_i - v_S) - \dfrac{v_o - v_S}{r_o} = 0$ (12)

Using (6) in (12)

$\dfrac{v_S}{R_S} - g_m(v_i - v_S) + \dfrac{v_S}{r_o} + \dfrac{R_D}{R_S \cdot r_o} v_S = 0$ (13)

$v_S\left(\dfrac{1}{R_S} + g_m + \dfrac{1}{r_o} + \dfrac{R_D}{R_S \cdot r_o}\right) - g_m v_i = 0$ (14)

$v_S = \dfrac{g_m v_i}{\dfrac{1}{R_S} + g_m + \dfrac{1}{r_o} + \dfrac{R_D}{R_S \cdot r_o}}$ (15)

$v_o = -\dfrac{R_D}{R_S} \cdot \dfrac{g_m v_i}{\dfrac{1}{R_S} + g_m + \dfrac{1}{r_o} + \dfrac{R_D}{R_S \cdot r_o}} =$ (16)

$= -\dfrac{g_m R_D v_i}{1 + g_m R_S + \dfrac{R_S}{r_o} + \dfrac{R_D}{r_o}} =$ (17)

$= -\dfrac{g_m R_D v_i}{1 + g_m R_S + \dfrac{1}{r_o}(R_S + R_D)}$ (18)

$A_{vo} = \dfrac{v_o}{v_i} = -\dfrac{g_m R_D v_i}{1 + g_m R_S + \dfrac{1}{r_o}(R_S + R_D)} \cdot \dfrac{1}{v_i}$ (19)

$A_{vo} = \dfrac{v_o}{v_i} = -\dfrac{g_m R_D}{1 + g_m R_S + \dfrac{1}{r_o}(R_S + R_D)}$ (20)

For $\lambda = 0 \Rightarrow r_o = \infty$

$A_{vo} = \dfrac{v_o}{v_i} = -\dfrac{g_m R_D}{1 + g_m R_S}$

In-class Problem 2, Solution

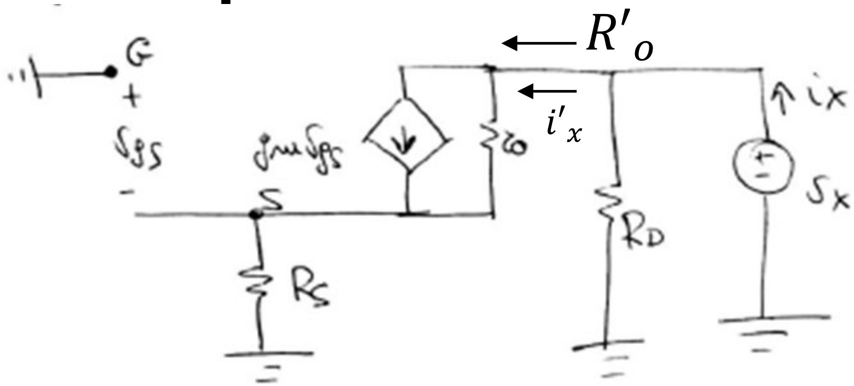
The open circuit voltage gain and the amplifier gain are the same in this example as there is no load connect at the output terminal.

The overall voltage gain is

$$G_v \approx -\frac{g_m R_D}{1 + g_m R_S} \times \frac{R_1 \parallel R_1}{R_1 \parallel R_1 + R_{sig}}$$

In-class Problem 2, Solution

Output resistance



$$R_o = \frac{v_x}{i_x}$$

$$R_o = R_D \parallel R'_o$$

Determine R'_o

$$R'_o = \frac{v_x}{i'_x} \qquad (1)$$

$$v_{gs} = -v_s \qquad (2)$$

KCL at S

$$\frac{v_s}{R_s} + \frac{v_s - v_x}{r_o} - g_m(-v_s) = 0 \quad (3)$$

$$\frac{v_s}{R_s} = \frac{v_x}{r_o + (1 + g_m r_o)R_s} \quad (4)$$

$$i'_x = \frac{v_s}{R_s} = \frac{v_x}{r_o + (1 + g_m r_o)R_s} \quad (5)$$

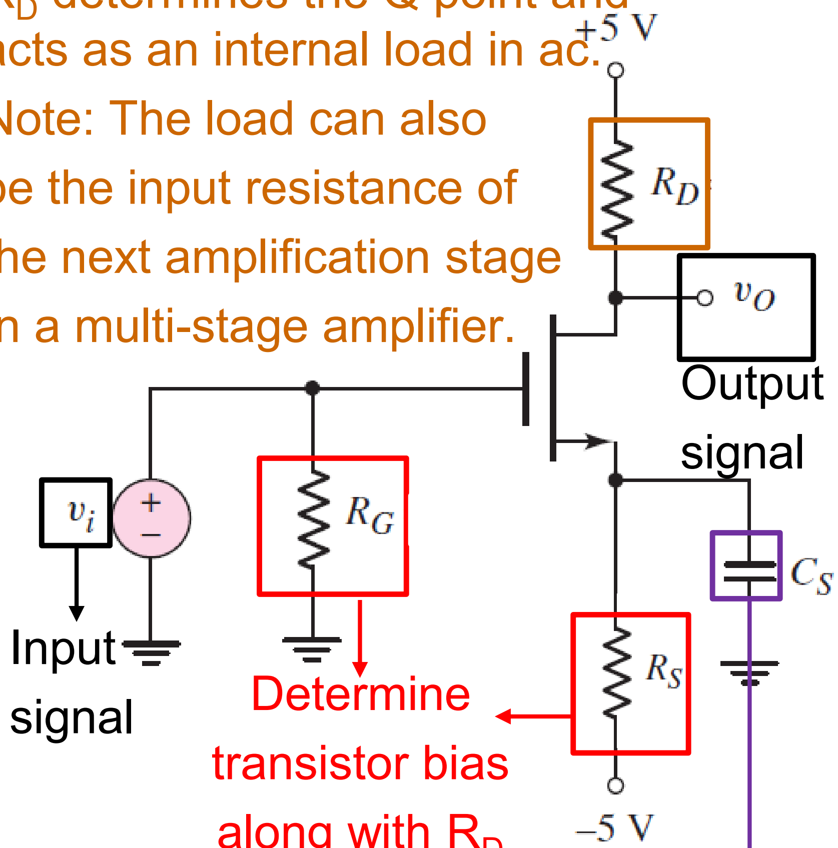
$$\frac{1}{R'_o} = \frac{v_x}{i'_x} = \frac{1}{r_o + (1 + g_m r_o)R_s} \quad (6)$$

$$R_o = R_D \parallel [r_o + (1 + g_m r_o)R_s] \approx R_D$$

Common Source (CS) Amplifier w/ Bypass Capacitor

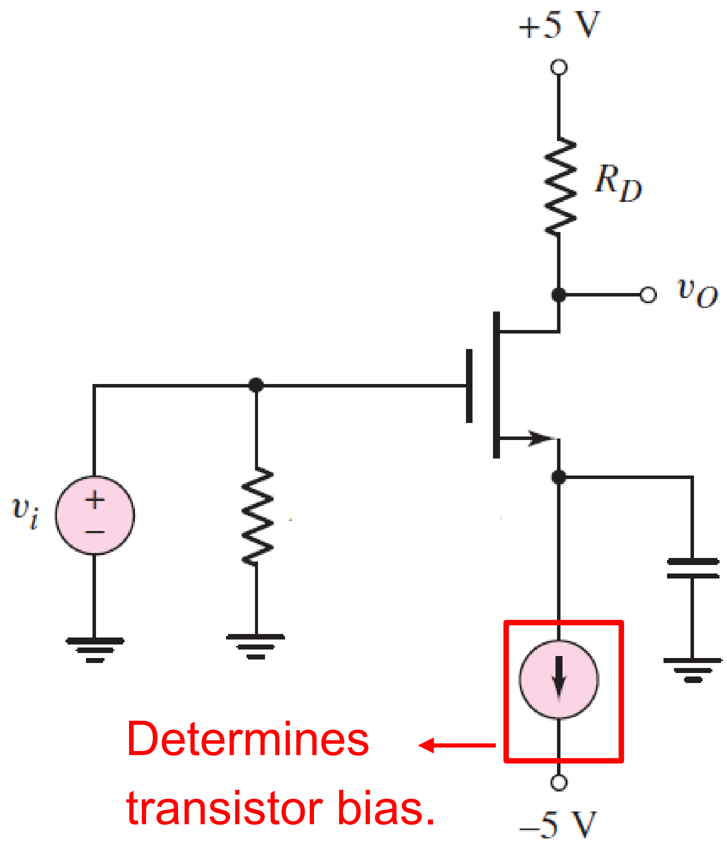
R_D determines the Q point and acts as an internal load in ac.

Note: The load can also be the input resistance of the next amplification stage In a multi-stage amplifier.



Determine transistor bias along with R_D V_{DD} and V_{SS}

Bypass capacitor: It minimizes the loss in the gain due to the resistor on the source

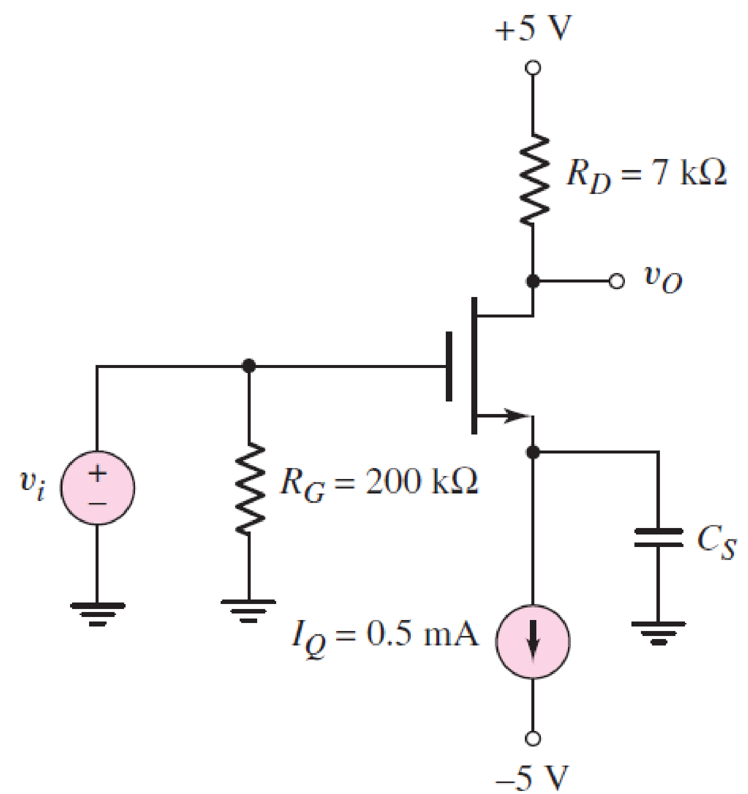


Determines transistor bias.

Note: the internal resistance of a real current source would affect the Q point just as R_s in the circuit on the lhs.

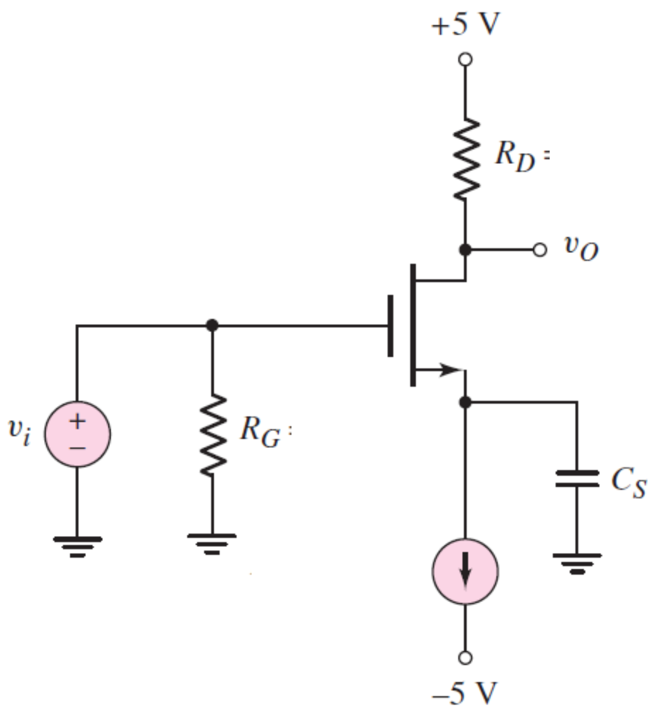
In-class Problem 3

Sketch the AC and the small-signal equivalent circuit of the common source amplifier below. Determine the expressions for the input and output resistance, for the open circuit voltage gain, the amplifier gain and the overall voltage gain. Assume the frequency of the input signal is midrange, i.e., high enough for the coupling capacitor C_{C1} to act as a short circuit in ac but low enough for the gate capacitor to act as an open circuit in ac.

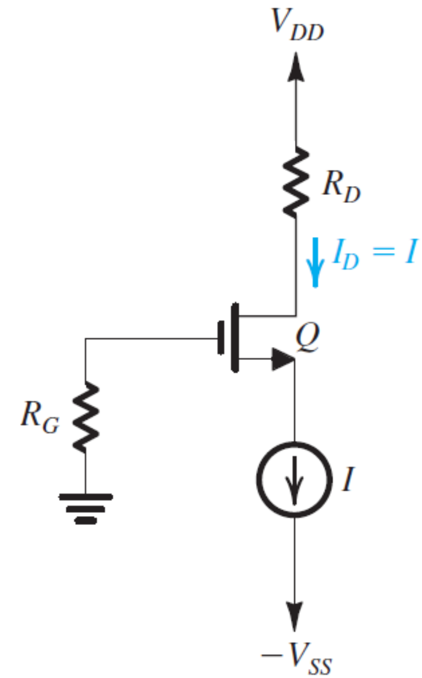


Consider λ=0

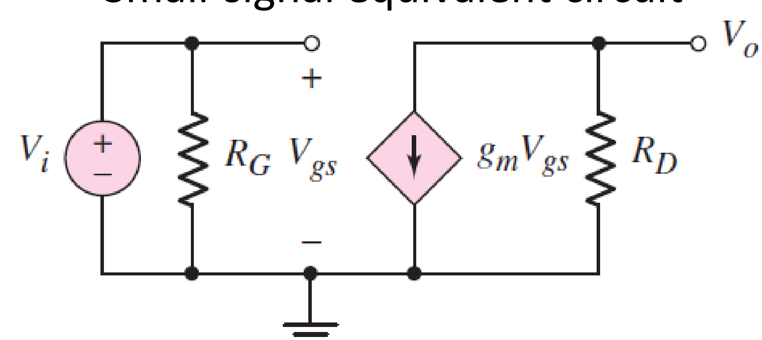
In-class Problem 3, Solution



DC circuit

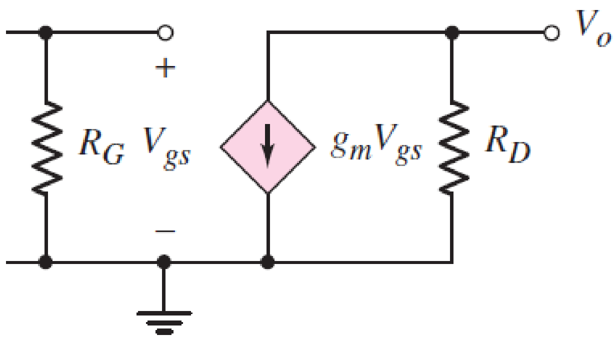


Small-signal equivalent circuit

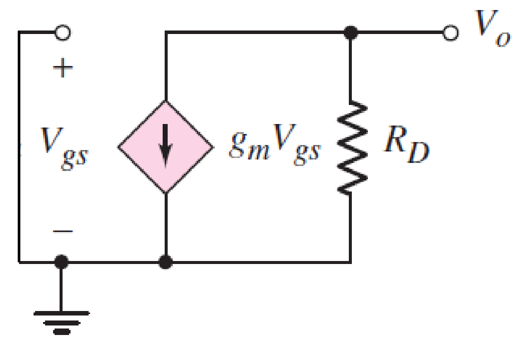


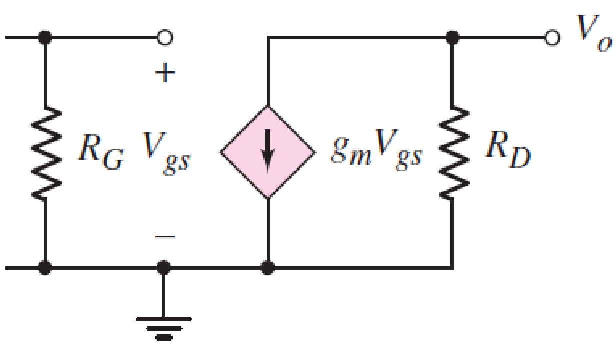
In class Problem 3, Solution

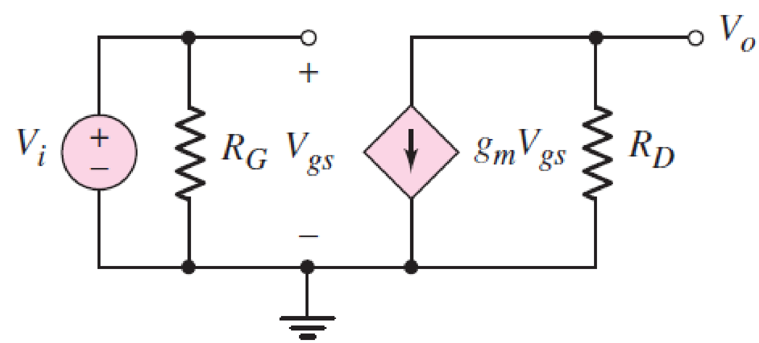
R_i=R_G



R_o=R_D







R_o=R_D

Overview of Lecture 7

- Basic amplifier configurations
- Common source (CS) FET amplifiers (Neamen 4.3, S&S 5.6.3, 5.6.4)
- Common Gate (CG) FET amplifiers (Neamen 4.5, S&S 5.6.5)
- Common Drain (CD) FET amplifiers (Neamen 4.4, S&S 5.6.6)
- Comparison among the three configurations (Neamen 4.6, S&S 5.6.7)